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This paper will primarily seek to answer the following question: With the future proliferation of armed UAVs in the battlespace, can the current Command and Control (C2) doctrine effectively employ the full range of capabilities of these systems? The research focused on the current concept of operations (CONOPS) for the primary system in use, the MQ-1 Predator as well as the Air Force's newest armed UAV, the MQ-9 Hunter-Killer. The future technologies being developed for the next generation of armed UAV systems, namely the Joint Unmanned Combat Aerial System (J-UCAS) and the Unmanned Combat Armed Rotocraft (UCAR) were evaluated in order to access the viable range of missions for future operations. Since both of these programs are joint ventures with planned multi-service employment, the individual service perspectives and the need for joint service doctrine were considered and incorporated as well. Based on the research conducted and analysis of material, it is clear that the full integration of armed UAVs into the future battlespace will require fundamental changes to the current C2 structure and doctrine.

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<u>Armed UAVs in the Future Battlespace – The Need for Command and Control Doctrine</u>

By

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Lieutenant Commander, USN

A paper submitted to the faculty of the Naval War College in partial satisfaction of the requirements of the Department of Joint Military Operations.

The contents of this paper reflect my own personal views and are not necessarily endorsed by the Naval War College or the Department of the Navy.

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14 February 2005

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Abstract

This paper will primarily seek to answer the following question: With the future proliferation of armed UAVs in the battlespace, can the current Command and Control (C2) doctrine effectively employ the full range of capabilities of these systems? The research focused on the current concept of operations (CONOPS) for the primary system in use, the MQ-1 Predator as well as the Air Force's newest armed UAV, the MQ-9 Hunter-Killer. The future technologies being developed for the next generation of armed UAV systems, namely the Joint Unmanned Combat Aerial System (J-UCAS) and the Unmanned Combat Armed Rotocraft (UCAR) were evaluated in order to access the viable range of missions for future operations. Since both of these programs are joint ventures with planned multi-service employment, the individual service perspectives and the need for joint service doctrine were considered and incorporated as well. Based on the research conducted and analysis of material, it is clear that the full integration of armed UAVs into the future battlespace will require fundamental changes to the current C2 structure and doctrine.

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INTRODUCTION

The future battlespace is envisioned to include a multitude of unmanned vehicles, particularly Unmanned Aerial Vehicles (UAVs) and Unmanned Combat Aerial Vehicles (UCAVs), which are essentially armed or weaponized UAVs.[1] The employment of armed UAVs has grown exponentially since concept inception and testing in early 2001 and their first operational use in Afghanistan in 2002. Since that time, MQ-1 Predators have evolved from being purely Intelligence, Surveillance and Reconnaissance (ISR) platforms to highly capable strike assets employed on missions ranging from engagement of High Value and Time Sensitive Targets (HV/TSTs) to Close Air Support (CAS) in urban environments. The increased operational use of armed Predators, coupled with the multitude of armed UAVs under current development, promises to overwhelm the capability of the operational commander to effectively employ all of these assets unless fundamental changes are made to the current command and control (C2) structure and doctrine.

In the very near future, armed UAVs will go from relatively obscure weapons with limited capability to one of the most prevalent and sophisticated systems in the battlespace, with each of the services independently fielding multiple vehicles. In order to be effectively employed, armed UAVs will need an adaptive and flexible C2 doctrine which addresses their unique capabilities and limitations while facilitating the execution of their mission. Current C2 doctrine for armed UAVs does not account for their full range of capabilities nor their employment across services and in the joint environment. Based on the research and analysis

[1] The terms "armed" and "unarmed" unmanned aerial vehicles or UAVs are used for consistency and to denote a UAV that has been designed or modified to employ weapons as part of its primary mission. This is also the accepted definition for a UCAV, though presently there is no unanimity regarding terminology, and terms such as unmanned combat aerial vehicle, uninhabited combat aerial vehicle and remotely operated aircraft (ROA) are used interchangeably in source documents.

conducted, it is clear that the full integration of armed UAVs into the future battlespace will require fundamental changes to the current C2 doctrine.

The following three assumptions form the context and bound the findings and recommendations: (1) current Concepts of Operation (CONOPS) for armed UAVs are representative of future CONOPS; (2) armed UAVs will be fielded by each service independently, although an individual platform or system may be in use by multiple services; and (3) missions for armed UAVs will be similar to current missions performed by both manned and unmanned platforms and will serve a range of strategic, operational and tactical objectives.

Although the CONOPS and C2 for armed UAVs are closely related to unarmed UAVs both in practice and envisioned future employment, the two are treated as distinctly different in this discussion. The reason for this distinction is that unarmed UAVs are generally employed in ISR missions closely linked to the intelligence requirements of the operational commander. This link necessitates a direct relationship with the intelligence infrastructure that resides at the operational and theater strategic levels and therefore requires that C2 of these ISR assets remain at the operational level or above. Small or micro UAVs are also not considered in this paper due to their limited capability and tactical mission focus.[2]

[2] Small or micro UAVs are typically man-portable and handheld UAVs designed to perform basic surveillance and reconnaissance missions with simple electro-optical sensors and minimal support hardware. Currently there are no planned armed UAVs being developed to be man-portable or designed to provide stand-alone support for small units (platoon level or below).

Armed UAVs in the Current Battlespace

The United States' first experience with arming UAVs occurred in the closing days of the Vietnam conflict when engineers from Teledyne Ryan Aeronautical placed AGM-65 Maverick missiles on a Model 234 remotely piloted vehicle.[3] In a December 1971 test, a Model 234 operator, using queuing from an on-board television camera system, launched two missiles at a radar control van in a simulated surface-to-air missile site in the Nevada desert, scoring one direct hit.[4] This was the first successful air-to-surface missile firing from an unmanned vehicle and even though the armed drone concept was abandoned for other weapons systems, this event paved the way for the operational use of modern armed UAVs.

In November 2002, a RQ-1 Predator UAV fired two AGM-114 Hellfire missiles into a vehicle containing six Al-Qaeda operatives as it traveled down a desert road east of the Yemeni capitol of Sana'a, debuting a capability that the Air Force had secretly developed and tested in early 2001 and first used in combat in Afghanistan in March of 2002. [5] From early operational experiences in Operation Enduring Freedom (OEF), and later in Operation Iraqi Freedom (OIF), a generally accepted concept of operations developed which utilized the existing C2 structure of the ISR Predator to integrate the armed version into combat missions.

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[3] For a complete history of the Model 234 and Firebee Drone program, see either Michael Armitage, *Unmanned Aircraft*, *Brassey's Air Power: Aircraft, Weapons Systems and Technology Series*, *vol. 3* (London: Brassey's Defence Publishers Ltd. 1988), or Andreas Parsch, *Teledyne Ryan Q-2/KDA/xQM-34/BGM-34 Firebee*, Lkd. Designation-Systems.net, "Directory of U.S. Military Rockets and Missiles." < http://www.designation-systems.net/dusrm/m-34.html> [14 January 2005].

[4] Michael Armitage, 81.

[5] Azadeh Moaveni, "They Didn't Know What Hit Them," *Time*, 18 November 2002, 58, ProQuest, [14 January 2005]; *Predator Unmanned Aerial Vehicle (UAV), USA*, Lkd. Airforce-Technology.com, <http://www.airforce-technology.com/project_printable.asp?ProjectID=1137> [14 January 2005]; James G. Roche, "Applying UAV Lessons to Transform the Battlefield" (Remarks at Association of Unmanned Vehicles Systems International, Baltimore, MD., 15 July 2003), Lkd. FindArticles.com, <http://www.findarticles.com/p/articles/mi_m0PDU/is_2003_July_15/ai_109569822> [16 May 2004].

Current C2 and Concepts of Operation

The initial Concept of Employment for the MQ-1 stated that the Predator was an operational level asset, with operational control (OPCON) normally delegated to the joint force air component commander (JFACC) by the joint force commander (JFC).[6] According to both doctrine and practice, tactical control (TACON) was delegated within the air component operational chain of command from the air operations officer (A3) to the Squadron Operations Center, tasked by the Air Tasking Order (ATO) process and operated under guidance from the Air Operations Center (AOC). Figure 1, illustrates the OPCON and TACON relationships as they currently exist.

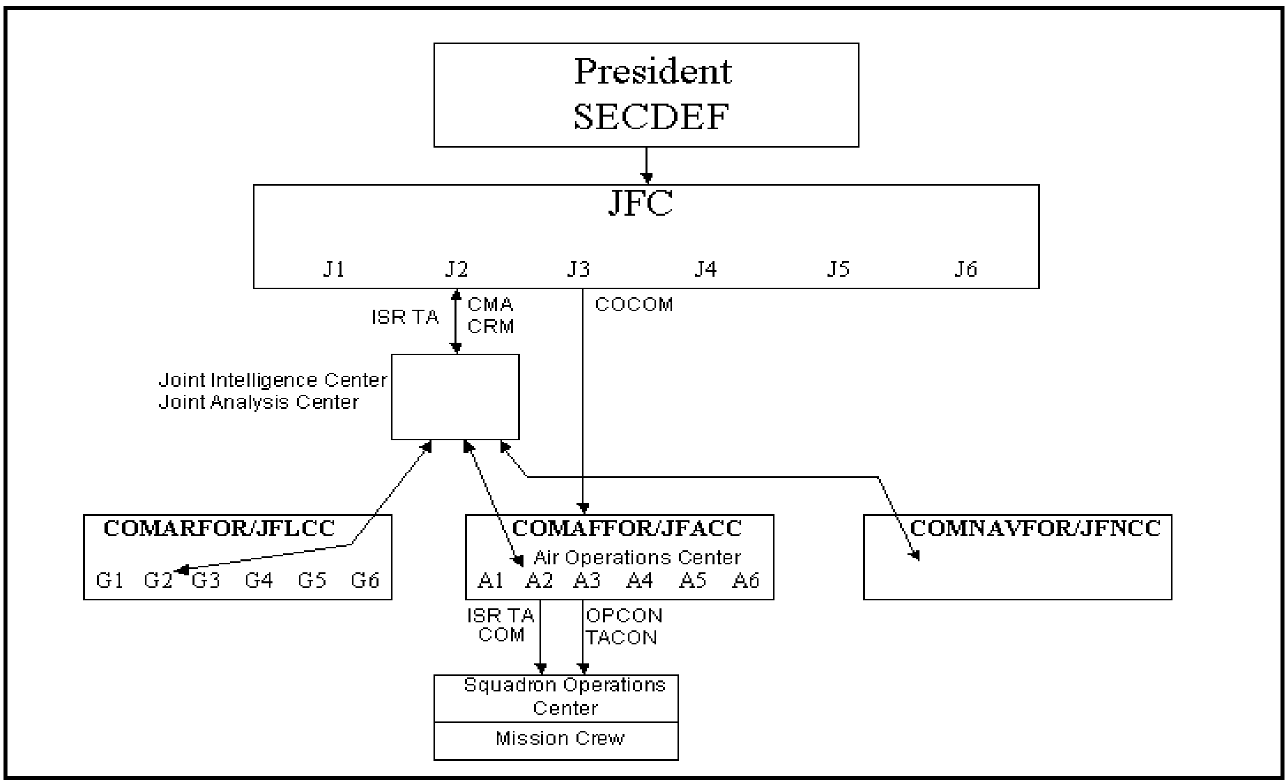

Figure 1. Current C2 Structure for the MQ-1 and MQ-9[7]

[6] United States Air Force Air Combat Command, *Concept of Employment for the MQ-1 and MQ-9 Multi-role Endurance Remotely Operated Aircraft*, (Langley AFB, Virginia: 2 May 2002), 19.
[7] United States Air Force Air Combat Command, *Enabling Concept MQ-9 Hunter-Killer*, (Langley AFB, Virginia: 16 July 2004), 47.

Functionally, Predators were tasked in OEF and OIF for primarily ISR missions, but TACON for direct attack missions typically remained at the AOC, sometimes requiring authorization as high as the Secretary of Defense for weapons release. The majority of these missions fell under the heading of Time Sensitive Targets (TST),[8] (often command leadership or mobile targets) which due to either their sensitive nature or to collateral damage concerns, required higher level approval prior to engagement.

In operations such as OIF, MQ-1 Predators were considered to be operational level assets despite being employed in a number of tactical level missions and roles. Lieutenant General Walter E. Buchanan III, current commander of U.S. Central Command Air Forces (CENTAF) and the Central Command Combined Forces Air Component Commander (CFACC), classified Predator as an "operational system able to range the full depth and breadth of the battlespace."[9] Additionally, he went on to state that "doctrinally, CENTCOM employs UAVs in a layered approach across the battlefield with shorter range, tactical systems in direct support of deployed units while more flexible, longer range systems are used to range the theater in general support responding to priorities set by CENTCOM and the supported joint task force commanders."[10] Lieutenant General Buchanan detailed representative missions when Predators were employed to include "traditional ISR collection, high value targeting (HVT), interdiction, close air support, force protection, MANPAD/counter-mortar suppression, combat search and rescue, SOF infiltration and

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[8] Time Sensitive Targets are defined as those targets requiring immediate response because they pose (or will soon pose) a clear and present danger to friendly forces or are highly lucrative, fleeting targets of opportunity. Department of Defense, Department of Defense Dictionary of Military and Associated Terms, Joint Pub JP 1-02 (Washington, DC: 12 April 2001, As Amended Through 30 November 2004), 540.

[9] Walter E. Buchanan III, Testimony before the House Armed Services Committee, United States House of Representatives, Subcommittee on Tactical Air and Land Forces, "Unmanned Combat Air Vehicle (UCAV) and Unmanned Aerial Vehicle (UAV)," 17 March 2004, Lkd. GlobalSecurit.org, <http://www.globalsecurity.org/ military/library/congress /2004_hr/04-03-17buchanan.htm> [16 May 2004] .

[10] Ibid.

exfiltration and battle damage assessment."[11] Though many of these missions are indeed operational in terms of the level of coordination and effect, it is hard to envision missions such as CAS, force protection, and counter-mortar suppression residing above the tactical level. What General Buchanan detailed quite effectively is the fact that operational level assets (Predators) were being used routinely for tactical level missions utilizing a C2 structure that did not delegate TACON to the supported tactical commander. In practice, this removes control from the tactical commander - who is arguably in the best position to make employment decisions - to the operational commander - who in theory should not be concerning himself with the level of detail necessary to make sound tactical decisions.

In the case of Predator, the necessity of maintaining its command and control at the operational level stemmed from its role, first as an ISR platform, and later as a multi-mission platform to engage TSTs. Once the functional capabilities of Predator were demonstrated, its concept of operations expanded to encompass a wider variety of missions.[12] Unfortunately, the C2 structure that was initially laid out to facilitate its operational level missions was never adjusted to account for the times when it would serve at the tactical level. Predator's ability to flex between missions that may reside at differing ends of the effects spectrum, (from the tactical level to the operational level and perhaps even as high as the strategic level), presents the combatant commander with the challenge of determining the appropriate level for the system's C2. As the first armed UAV in the modern battlespace, the Predator C2 structure became the de facto model for the Air Force's follow-on armed UAVs even

[11] Ibid.
[12] This phenomenon is commonly referred to as "mission creep." Mission creep is a term used to describe the expansion of a weapon system's mission beyond its original intent, usually due to increased capabilities, new technology or a lack of viable alternatives to fill the role.

though it was never intended to support a multi-mission vehicle like the MQ-1 or MQ-9 Hunter-Killer.

The Service Models

Presently, concepts for C2 of future armed UAVs have developed along three distinct paths, all of which are primarily service driven. The Air Force vision for the employment of the MQ-9 follows closely its current doctrine for MQ-1 employment, as an operational level asset functioning in either a supported or supporting role with most employment decisions being made at the level of the functional component commander or above.[13] The Air Force considers armed UAVs as platforms that directly support the task force commanders, which should be directed and controlled at the operational level. Its future armed UAV, the X-45C currently under development as part of the Defense Advanced Research Projects Agency (DARPA) J-UCAS program, will most likely follow this same doctrinal construct.

The Navy's vision for future armed UAV operations is similar in some aspects to the Air Force's vision, but since the Navy intends to integrate its armed UAVs into the environment of the aircraft carrier, C2 will reside at the tactical level. Similar to current Carrier Air Wing (CVW) aircraft, they will function as supporting assets for either the commander of the Carrier Strike Group (CSG) or for the functional component commanders when employed as part of a JTF.

The Army and the Marine Corps will likely take a dramatically different approach to the command and control of their armed UAVs. Both services typically view their organic air assets as an extension of the ground commander, providing direct support for the ground forces at the tactical level. Marine Corps doctrine places C2 of rotary and fixed wing aircraft

[13] ACC, *Enabling Concept MQ-9 Hunter-Killer*, 47.

with the Aviation Combat Element (ACE) of a Marine Air-Ground Task Force, while the Army establishes the C2 at the brigade level. The Army's future armed UAVs are being developed as part of the Future Combat System (FCS) concept, which envisions four different classes of UAVs tied to distinct organizational levels. The Class III and IV UAV will likely be armed and will reside at the battalion and brigade levels respectively, while the Class II and Class I vehicles will provide an organic ISR capability at the Company and Platoon level. With the FCS concept, the Army clearly intends to retain C2 of its armed UAVs at the tactical or "unit of action" level and below.

Service Model Issues

There are two problems with trying to integrate armed UAVs under the C2 structures that presently exist for traditional UAVs and manned aircraft. First, the service-driven models fail to account for the unique capabilities of armed UAVs, such as their ability to be dynamically retasked and engage HV/TSTs. Second, the C2 doctrines of all three service models fail to adequately balance the differences between employment at the operational level and the tactical level. While the operational level C2 structure risks ineffective employment at the tactical level, the tactical level C2 structures compound the problems of airspace deconfliction and mission overlap.

The Air Force model of utilizing operational level C2 to support tactical missions exposes the operational commander to the risk of becoming too fixated on the details of one aspect of the battlespace to the detriment of the broader operational picture. It also has the added drawback of facilitating encroachment of the operational commander into the tactical decision making process, which becomes a means of "high-level micromanagement."[14] In order to justify employment at the operational level, there must genuinely be a requirement for armed UAVs to generate effects at that level. For example, if the authority to engage a specific target cannot be delegated below the operational level, that capability must reside with the operational commander. In reality, this possibility is limited to a few distinct target sets, typically HVTs of a sensitive nature, such as command leadership.

Other rationales for retaining control of armed UAVs at the operational level are asset allocation and safety of flight. While both are legitimate concerns to the operational commander, the best way to address safety of flight and airspace deconfliction issues is through existing airspace control doctrine. Likewise, the functional component commander has the means of asset allocation and management available to him through the normal ATO process, which is a much more efficient method of tasking than husbanding of assets. While both of these arguments may have had merit when managing a relatively small number of assets, they will clearly lose strength as more and more systems enter the battlespace.

Army and USMC structures for C2 of armed UAVs places control at the lower tactical levels which fails to adequately address the problems of deconfliction and mission overlap. Airspace deconfliction became an issue in OIF despite the limited numbers of tactical UAVs employed there, with at least one incident of a mid-air collision being reported between a Pointer UAV and an Army OH-58.[15] Although the size disparity between the two limited the damage to the manned platform, it does highlight the problems of integrating

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[14] Rand D. LeBouvier, "Unmanned Systems Extend Operational Reach," *United States Naval Institute Proceedings*, June 2004, 38.
[15] Association of the U.S. Army, *Budget Constraints Affect Aviation Programs*, 10 January 2005, Lkd. AUSA.org, <https://www.ausa.org/www/news.nsf/NonHomeFS?OpenFrameSet&Frame=Content&Src=%2Fwww%2Fnews.nsf%2F(searchresults)%2F4178fdd954d6374d85256f820050e7af%3FOpenDocument%26AutoFramed> [14 January 2005]. The FQM-151 Pointer UAV is a small hand launched UAV employed for real-time video surveillance. It has a nine foot wingspan and weighs approximately ten pounds. It has been in use by the Army since Desert Storm and is currently employed at the company level and below.

greater numbers of air vehicles into a confined battlespace. Airspace deconfliction is formally accomplished through the Airspace Control Order (ACO) and the ATO Special Instructions. The risk of mid-air collision is further mitigated through unit SOPs, positive aircraft control and handling, and standard "see and avoid" tactics. Integrating armed UAVs into this system will be mostly procedural and considerably easier than the challenges of deconflicting the hundreds of small, tactical UAVs which will be vying for the same airspace. This is a related but separate issue that still needs to be resolved.

The issue of mission overlap is likely to be much harder to solve with a tactical level C2 structure. With an increased number of armed UAVs operating in the same battlespace under differing C2 structures, there are obviously going to be times when two or more platforms will have overlapping and possibly conflicting mission requirements (Figure 2).

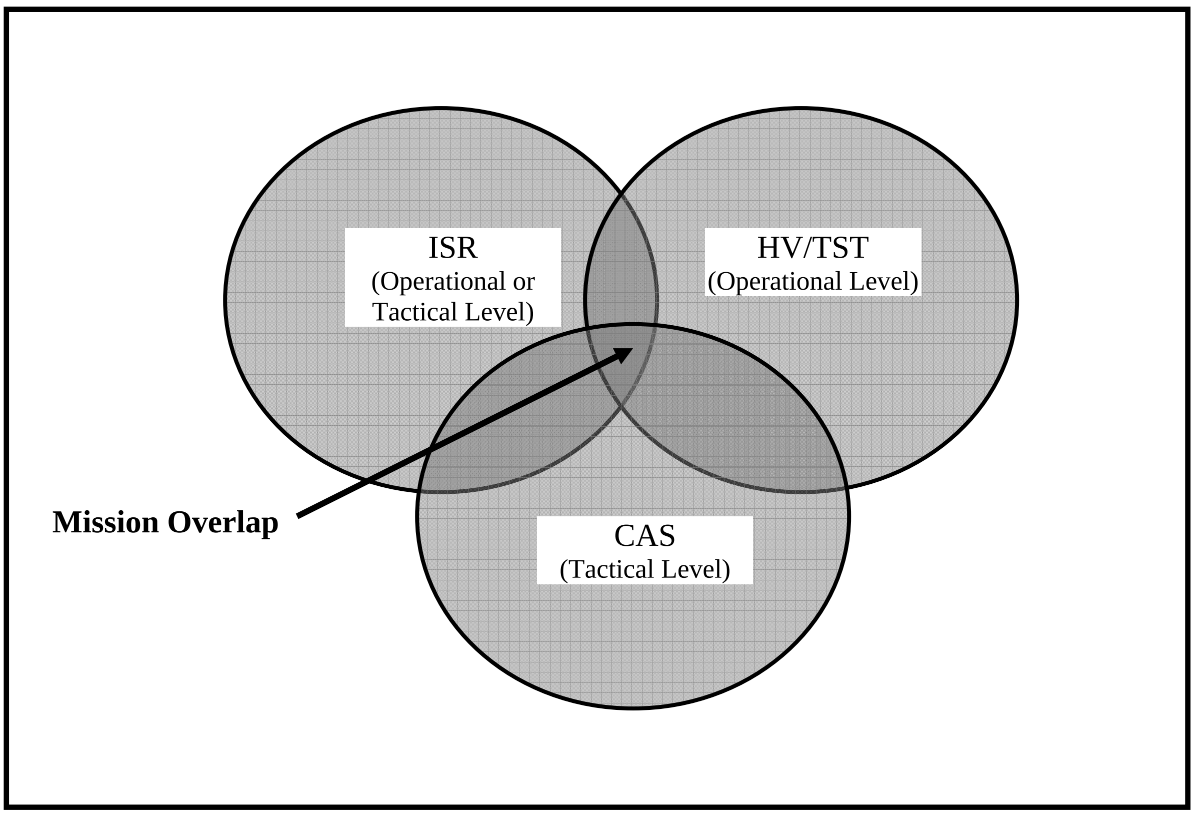

Figure 2. Operational and Tactical Mission Overlap

The most obvious conflicts occur between the operational and tactical levels, though conflicts at the same mission level are equally possible. Regardless of where it occurs, mission overlap can threaten mission success as well as decrease the efficiency of asset allocation. Coordinating the actions of numerous unmanned platforms operating at varying levels of command will be nearly impossible without a uniform C2 structure between the services, but it is also highly unlikely that any service will surrender the ability to independently employ their armed UAVs unless their service specific tactical needs are also addressed.

Armed UAVs in the Future Battlespace

The era of armed UAV employment is in its infancy, as illustrated by the fact that OIF utilized only seven MQ-1s and marked the first time that four Predators flew simultaneously during combat operations.[16] As technologies mature and the next generation of armed UAVs enter operational capability, a host of new problems will complicate the decision of where to locate command and control of these weapons systems. Several technological factors will impact the C2 of both current and future armed UAVs. These factors include: communications requirements, sensors and weapons, autonomous operations, and target recognition and identification.

The Impact and Limitations of Communications

Communication requirements are currently the single biggest limitation on the conduct of armed UAV operations and one of the top three technology challenges to enabling the full capability of future armed UAV systems.[17] Robust communications are considered the key to success for the current "system of systems" concept in which multiple sensors and platforms simultaneously share and analyze data in order to produce the desired effects on the enemy. The existing limitation to this concept is the throughput available using conventional communications and the electromagnetic frequency spectrum. The Defense Science Board noted that despite the dramatic increase in available bandwidth since Desert Storm (99 mbps), in OIF (3.2 Gigabytes per second) UAV operations were limited or delayed

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[16] United States Central Command Air Forces (CENTAF) Assessment and Analysis Division, *Operation IRAQI FREEDOM – By the Numbers* (Prince Sultan Air Base, Kingdom of Saudi Arabia: 30 April 2003), 7.
[17] Paul Waugh, "Challenges & Opportunities" (Remarks prepared for delivery at DARPATech 2004 Symposium, Anaheim, California, March 9-11, 2004), Lkd. DARPA.mil, <http://www.darpa.mil/DARPAtech2004/pdf/scripts/WaughScript.pdf> [28 December 2004].

due to the lack of frequency availability in the congested C-band spectrum.[18] Additionally, 84 percent of the available bandwidth in OIF was provided by commercial communications sources, which are less secure and more susceptible to jamming than military systems.[19] Developmental communication technologies such as the Global Information Grid (GIG)[20] may help to relieve the shortage of bandwidth, but for the foreseeable future, the growing number of UAVs and armed UAVs will continue to place increased demands on the limitations of the electromagnetic spectrum.

Sensor and Weapons Capabilities

Planned sensors and weapons for future armed UAVs will also play an important role in determining the level of C2 required for their employment. Current armed UAVs like the MQ-1 rely on electro-optical guided weapons such as the AGM-114C Hellfire, which is targeted either visually or with a Forward Looking Infrared sensor (FLIR) and then guided to the target via laser energy. This basic method requires operator interaction for all four phases of target engagement: acquisition, designation, weapon release, and terminal weapon guidance. Planned weapons for follow-on armed UAVs are primarily GPS/INS guided weapons such as the GBU-38 (500 lb. Joint Direct Attack Munition (JDAM)) and the GBU-39 (250 lb. Small Diameter Bomb (SDB)). Both of these are glide weapons that are guided to the preprogrammed target coordinates using GPS primarily, with an inertial navigation system (INS) for redundancy. While this decreases the requirements for operator input and facilitates autonomous operation, it also restricts the types of targets that can be engaged to

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[18] Department of Defense, *Defense Science Board Study on Unmanned Aerial Vehicles and Uninhabited Combat Aerial Vehicles* (Washington, DC: February 2004), 24.
[19] Ibid.
[20] Ibid., 25. The Global Information Grid is a concept under development to implement a military global Internet-like communication service by linking numerous systems into a secure information network.

fixed sites where there is reliable targeting data. Future weapons capability is planned to include a number of precision laser-guided munitions such as GBU-12 (500 lb. laser-guided bomb), laser-guided rocket systems and laser-guided gliding munitions.[21] While these types of precision guided weapons will facilitate the engagement of moving targets and TSTs, they also generate the added requirement for terminal weapon guidance from the delivery platform or another networked system.

Autonomous Operations Development

Nearly all future UAVs will have increased levels of autonomy in operation, meaning that they will rely less and less on operator input for functional control. Development of this capability will likely follow a tiered approach by introducing autonomous operations for routine tasks such as transit, take-off and landings, followed by increasing levels of mission autonomy to include weapon release against pre-planned fixed targets and standard reactions to threat indications and warnings. Independent autonomous operation will include target identification and engagement without a "man-in-the-loop" for target confirmation and weapon release authorization. The impetus behind increased autonomous operations is the desire to decrease the number of human operators required to employ future UAV systems and effectively increase the number of platforms that can be employed given current limitations on bandwidth.[22]

Coupled with autonomous operations are the concepts of "swarming" or group autonomous behavior, and "collaborative operations" as a means of employing multiple platforms acting in concert with each other and manned platforms. The Army intends to

[21] Bill Sweetman, "In the Tracks of the Predator: Combat UAV Programs Are Gathering Speed," *Jane's International Defence Review*, 01 August 2004, Lkd. Janes.com < www4.janes.com/K2/doc.jsp?t= Q&K2DocKey=/content1/janesdata/mags/idr/ history.htm> [21 January 2005].
[22] Paul Waugh, "Challenges & Opportunities."

incorporate the collaboration concept into its Future Combat System (FCS) Class IV UAV and Lockheed Martin as part of the DARPA UCAR program recently completed a demonstration simulating an operational mission with multiple UCAR vehicles and an AH-64D Apache Longbow helicopter.[23] As a precursor to collaborative operations, the current MQ-9 Hunter-Killer concept of employment envisions a single MQ-9 operating in concert with numerous assets to achieve required effects. This concept is dependent on using automated information exchanges between platforms and common theater channels in order to integrate the MQ-9 into the "system of systems" and to reduce required coordination and communication (Figure 3).[24]

[23] Lockheed Martin Corporation, *Lockheed Martin Demonstrates Collaboration of Manned, Unmanned Aircraft as Part of UCAR Development Program*, (Company Press Release, Owego, New York: 23 August 2004), <http://www.lockheedmartin.com/wms/findPage.do?dsp=fec&ci=15708&rsbci=0&fti=112&ti=0&sc=400> [20 January 2005].

[24] ACC, *Enabling Concept MQ-9 Hunter-Killer*, 28.

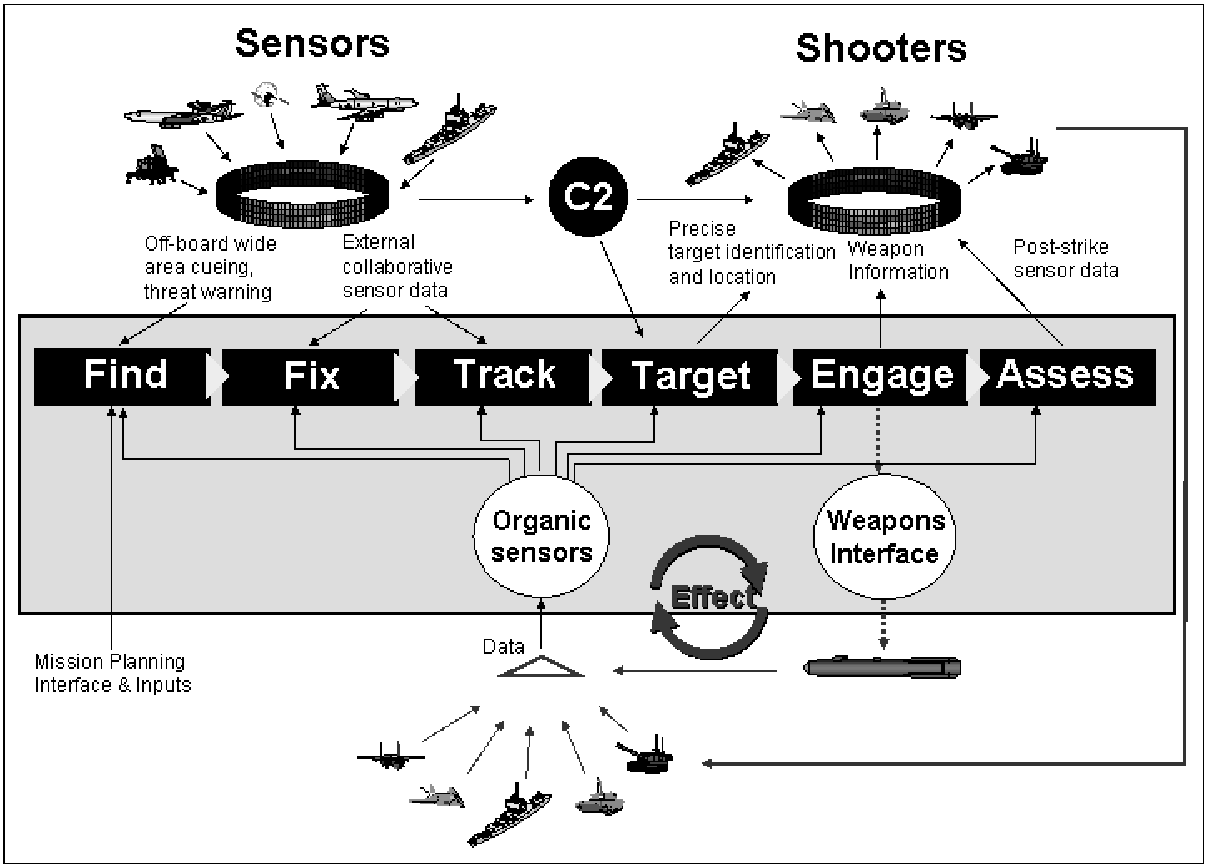

Figure 3. MQ-9 Integration and Interoperability[25]

The MQ-9 Hunter-Killer concept is obviously the stepping stone for future autonomous and collaborative operations between manned and unmanned systems. Although the discussion here is limited to UAVs, collaborative operations as envisioned by the Army's FCS concept includes unmanned ground vehicles as well,[26] and it is reasonable to expect that this concept will extend to include all manned and unmanned systems regardless of medium.

[25] Ibid., 29.
[26] *Future Combat Systems (FCS)*, Lkd. GlobalSecurity.org, <http://www.globalsecurity.org/military/systems/ground/fcs.htm> [19 October 2004].

Autonomous and collaborative operations both indicate that future UAVs will take a noticeable departure away from the traditional relationship of a dedicated operator or team of operators per vehicle. While this may serve to consolidate C2 functions at the tactical level, automatic target recognition capability may be a leading inhibitor to decentralizing the C2 structure for armed UAVs. While the technology required for an unmanned system to reliably identify and designate a target as hostile is still in development, current methodology for conveying target designation as well as typical Rules of Engagement (ROE) would severely limit the application of such a capability.[27] Until a reliable method for independently determining and designating a target as hostile is developed and vetted in operation, a "man-in-the-loop" will most likely be required prior to weapon's release on anything other than fixed targets. Additionally, the law of armed conflict effectively prohibits "weapons that are incapable of being controlled (i.e. directed at a military target)… as being indiscriminate in their effect."[28] While this generally isn't applied to weapons that operate independently within pre-programmed parameters, such as cruise missiles, it will play a key role when artificial intelligence is linked with target recognition. The moral and social implications of allowing armed UAVs to use artificial intelligence to target and engage hostile forces will have to be resolved prior to their introduction into the battlespace, as will the definition of an indiscriminate weapon.

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[27] Current systems like Link-16 and Blue Force Tracker can be used to label a known target as hostile for other disassociated platforms, but ROE typically requires that this designation alone does not meet weapon's release criteria. Clearance to fire typically requires that the target is correlated by both the designating and the shooting platform, deconflicted from known friendlies, a clear lane of fire exists, and collateral damage is mitigated. Many current systems for incorporating targeting data into a shared information grid are designed to be "exclusionary" rule based systems, which seek to identify "friendly" forces and exclude them from the target set. Anything not identified as friendly must still be positively identified as "hostile," and ROE must be satisfied prior to engagement. The over-arching factor driving these limitations is the necessity of preventing fratricide even at the risk of failing to accomplish the mission objective.

[28] Department of the Navy, *The Commander's Handbook on the Law of Naval Operations* (Naval Doctrine Command: Norfolk, Virginia: October 1995), 9-1.

Automatic target recognition and engagement capability is currently the biggest hurdle in the path of independent autonomous operation by armed UAVs, but the desire to continue with its development remains high. Until the technology matures and the remaining issues are resolved, the desire to increase autonomy to the level of independent operations will have to be balanced by the requirement for a "man-in-the-loop" when weapons are employed. The determination of where that "human" resides in the C2 structure will impact the ability of the operational commander to employ armed UAVs.

Emerging Technology and Mission Application

As technology matures and develops, the mission capability for armed UAVs will continue to expand in much the same way that the original RQ-1 Predator progressed from a pure ISR platform to a true multi-mission vehicle. Since Desert Storm, UAV and armed UAV missions have increased dramatically, to a point that only the most complex missions are considered beyond the limits of their capabilities. Most of the missions presently being excluded from consideration for armed UAVs entail a great deal of deductive reasoning and highly complex decision making, which would require an advanced level of artificial intelligence to replicate. Airborne early warning (AEW) and air-to-air combat are two such missions, and possibly to a lesser degree, anti-submarine warfare (ASW), and reactive suppression of enemy air defenses (SEAD). Figure 4, depicts the host of missions that armed UAVs are capable of performing given current or developing technology, compared to the missions other manned and unmanned assets currently perform. Although threat level and complexity may be a continuum based on a number of factors, the graphic representation does provide a fair comparison for a single generic scenario.

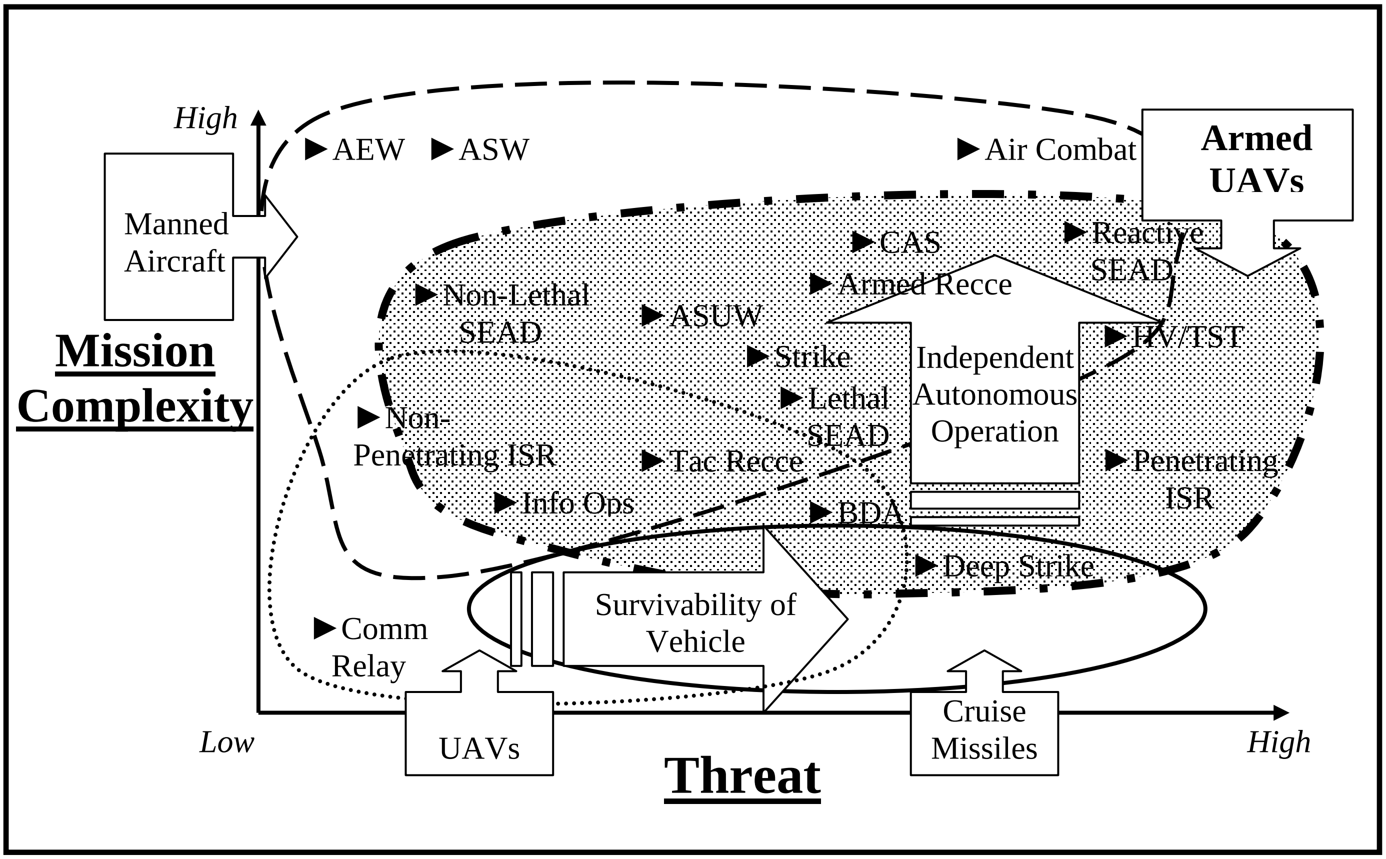

Figure 4. Mission Capabilities[29]

Currently, the primary limitation to mission capability for armed UAVs is whether or not the technology is achievable to attain the desired effects. Although platform selection should not be the overriding factor in mission tasking, armed UAVs clearly offer the operational commander a viable option for nearly all of the aviation missions in the modern battlespace. As evidenced by General Buchanan's remarks, armed UAVs are already being employed in varying degrees in a multitude of missions at both the operational and tactical levels, and their involvement is likely to continue to increase.

[29] Adapted from Chuck Pinney, *UAV Weaponization*, (Presentation delivered at International Air & Space Symposium (AIAA) "The Next 100 Years" 17 July 2003), Lkd. Raytheon.com, <http://www.raytheon.com/ feature/stellent/groups/public/documents/legacy_site/ cms01_042879.pdf> [28 December 2004]. The author has modified the diagram to reflect his own ideas and bears all responsibility for differences from the source.

Recommendations

The current Unmanned Aerial Vehicles Roadmap 2002-2007 states that the Air Force X-45, being developed as part of the DARPA J-UCAS program, is expected to IOC in 2010 with the Navy version following in 2015.[30] By the time the X-45 enters the scene, the MQ-9 will have been in full rate production for two years and employed operationally for at least five. As early as 2012, the Army could begin to field the first UCARs as their Class IV FCS vehicle,[31] supplementing the RQ-8 Fire Scout already planned for use as their Class III/IV UAV. In as few as seven years, armed UAVs will go from relatively obscure weapons with limited capability to one of the most prevalent and sophisticated systems in the battlespace, being operated independently by each of the services. Comparatively, in OIF a total of seven MQ-1 Predators were employed during the major combat phase of operations, with no more than four employed concurrently.[32] Based on the number of developmental programs alone, it is clear that armed UAVs are going to continue to appear in the modern battlespace in ever increasing numbers. The absorption of these assets into the current C2 structure for UAVs is not currently possible given the numbers and range of their capabilities, which will necessitate changes to both doctrine and structure prior to their full operational introduction.

Future Armed UAV Employment

What emerges from all of the above discussion is a myriad of employment possibilities for armed UAVs, ranging from the operational level to the tactical level and nearly across the full spectrum of missions. This expands even further when considering that

[30] Department of Defense, *Unmanned Aerial Vehicles Roadmap 2002-2027* (Washington, DC: December 2002), 12.
[31] *DARPA/Army Unmanned Combat Armed Rotorcraft (UCAR)Program Fact Sheet*, Lkd. DARPA.mil <http://www.darpa.mil/tto/programs/UCAR/ucar_summary.pdf> [29 December 2004].
[32] CENTAF, *Operation IRAQI FREEDOM - By the Numbers*, 7.

armed UAVs may be operating either alone or in collaborative groups and possibly conducting missions with varying degrees of autonomy. No single doctrine for C2 of armed UAVs would adequately suffice given the breadth of their mission requirements and capabilities. Flexible C2 organizational structures that can maximize the potential of these weapons systems while at the same time adequately address the unique challenges of integrating armed UAVs into the battlespace are going to be required. Doctrinally, a C2 structure that can balance mission requirements, desired effects, and the priorities of the operational level commander is necessary **prior** to the introduction of these assets to the battlespace. Unfortunately, that C2 structure does not currently exist even though armed UAVs are being introduced and employed at an ever-increasing rate.

Integration Considerations

As a whole, the concept of how to integrate and employ armed UAVs into the battlespace can be simplified by accepting them as technological evolutions of manned combat aircraft. In the first spiral of their development, they represent little more than advanced air vehicles with the pilot in a separate location.[33] Embracing the technology as evolutionary makes the tasks of integration much less daunting and provides a means to build upon existing employment tactics, techniques, and procedures. This is where C2 doctrine needs to begin, leveraging the models and structures currently in place for manned aircraft to develop new ones, rather than trying to randomly inject them into structures, based on service preference, related systems, or legacy platforms. This does not imply that armed UAVs don't deserve separate consideration of their unique capabilities and limitations, but rather that the basics of employment to include command and control, training, and support, must

[33] This is quite similar to the concept that has been in practice in the aviation test communities for years using F-4s, F-16s and other formally manned aircraft modified to be controlled remotely.

be put into doctrine **before** effective integration can occur. If armed UAVs are allowed to arrive on the scene without a clearly defined plan for how they will be implemented into the existing C2 structures, the operational commander can never hope to capitalize on the full extent of their capabilities.

Currently there is no single C2 doctrine that can fully employ the range of capabilities that armed UAVs promise. Though each of the three service-driven doctrines meets the short-term needs of its respective service, they all fail to adequately address the problems that are likely to occur in a joint battlespace. There are a multitude of employment considerations that cannot even be addressed until a coherent joint doctrine is developed and instituted. The call for development of joint doctrine is not new, and was in fact a key recommendation made by the Defense Science Board (DSB) in their February 2004 study on Unmanned Aerial Vehicles and Uninhabited Combat Aerial Vehicles, which recommended that Joint Forces Command (JFCOM) be tasked with the development of the doctrine and tactics necessary for the integration of UAVs into the force structure.[34] The DSB also emphasized the importance of considering "cross-service" use of systems when developing doctrine, as well as consideration for employing existing systems in an effort to accelerate the fielding of future UAVs.[35]

Proposed C2 Structure

A proposed C2 structure that resides at the upper levels of tactical command but well below the functional component commanders is presented below (Figure 5). This type of structure would retain the access of the tactical commander to armed UAV assets, while still

[34] Department of Defense, Defense Science Board Study on Unmanned Aerial Vehicles and Uninhabited Combat Aerial Vehicles (Washington, DC: February 2004), 12.
[35] Ibid., 10.

addressing the objectives and unique needs that exist at the operational level. In effect, it eliminates the propensity of the operational commander to become too engrossed in the tactical use of armed UAVs, while still retaining the ability to prioritize and task assets to meet his operational objectives.

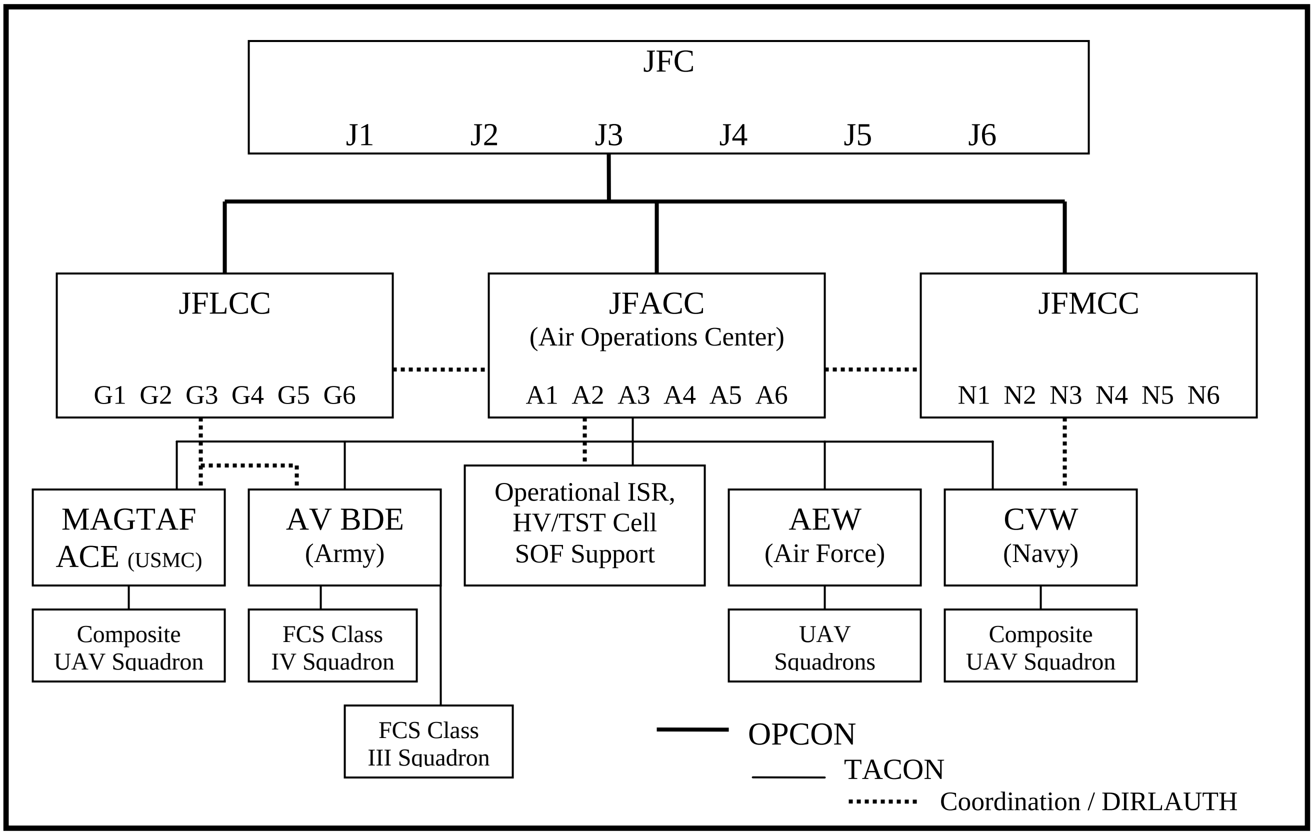

Figure 5. Proposed C2 Structure for Armed UAVs

The added benefit of this proposed structure is that it mirrors the one presently in use by both fixed-wing and rotary-wing manned assets in all of the services. The greatest deviation from current C2 structures is the consolidation of both Army and USMC armed UAVs under OPCON of the JFACC. This supporting/supported relationship is obviously at the discretion of the combatant commander, but facilitates both tactical and operational objectives while addressing the issues of airspace deconfliction and mission overlap. A further recommendation is that the JFACC retain TACON of a limited number of armed UAVs specifically for the HV/TST mission and Special Operations Forces (SOF) support when required. The C2 of these assets could easily be integrated into the current C2 structure for operational level ISR UAVs since the mission requires both J2 and J3 support to conduct effectively.

Conclusion

Prior to IOC of the first Air Force J-UCAS vehicles in 2010, there needs to be a formal reevaluation of the missions and roles of future armed UAVs taking into account their unique capabilities and limitations. The key to developing a workable C2 structure is balancing the mission requirements of the operational and tactical levels within the same structure to enable seamless employment at either level. Likewise, a joint approach to armed UAV integration must be developed to prevent employment from becoming too service-centric in either structure or method. Developing this doctrine now is critical in order to enable armed UAVs to meet their full mission potential and to integrate them completely into the future battlespace. Armed UAVs are great force enablers that have proved their utility and military worth to the operational commanders in Afghanistan, Iraq, and other regions where the Global War on Terror is being fought. They will undoubtedly continue to play a major role in delivering the desired effects in the battlespace of the future, but before they can be fully integrated and their potential maximized, fundamental changes must be made to their command and control doctrine.

Bibliography

Armitage, Michael. *Unmanned Aircraft, Brassey's Air Power: Aircraft, Weapons Systems and Technology Series, vol. 3.* London: Brassey's Defence Publishers Ltd., 1988.

Association of the U.S. Army. *Aircraft Survivability Top Army Aviation Priority*. Lkd. AUSA.org. 7 January 2005. <https://www.ausa.org/www/news.nsf/NonHomeFS?OpenFrameSet&Frame=Content&Src=%2Fwww%2Fnews.nsf%2F(searchresults)%2F4178fdd954d6374d85256f820050e7af%3FOpenDocument%26AutoFramed> [14 January 2005].

________. *Budget Constraints Affect Aviation Programs*. Lkd. AUSA.org. 10 January 2005. <https://www.ausa.org/www/news.nsf/NonHomeFS?OpenFrameSet&Frame=Content&Src=%2Fwww%2Fnews.nsf%2F(searchresults)%2F4178fdd954d6374d85256f820050e7af%3FOpenDocument%26AutoFramed> [14 January 2005].

________. *Commanders Better Understand Value of Army Aviation*. Lkd. AUSA.org. 7 January 2005. <https://www.ausa.org/www/news.nsf/NonHomeFS?OpenFrameSet&Frame=Content&Src=%2Fwww%2Fnews.nsf%2F(searchresults)%2Fd0f75c9df9c84e3b85256e14005e2d9a%3FOpenDocument%26AutoFramed> [14 January 2005].

Bartley, Michael L. "Unmanned Combat Aerial Vehicles: A Close Air Support Alternative." Unpublished Research Paper. Air War College Resident Program. Air University. Maxwell Air Force Base, Alabama: 9 December 2002.

Bone, Elizabeth, and Christopher Bolkcom. *Unmanned Aerial Vehicles: Background and Issues for Congress.* Washington, DC: Congressional Research Service. The Library of Congress. 25 April 2003. Order Code RL31872.

Buchanan, Walter E. III, Testimony before the House Armed Services Committee. United States House of Representatives. Subcommittee on Tactical Air and Land Forces. *Unmanned Combat Air Vehicle (UCAV) and Unmanned Aerial Vehicle (UAV).* 17 March 2004. Lkd. GlobalSecurity.org. <http://www.globalsecurity.org/military/library/congress/2004_hr/04-03-17buchanan.htm> [16 May 2004].

Cantrell, Mark. "The Pilot Who Wasn't There." *Military Officer*. Alexandria: January 2005. 46-53.

DARPA/Army Unmanned Combat Armed Rotorcraft (UCAR)Program Fact Sheet. Lkd. DARPA.mil <http://www.darpa.mil/tto/programs/UCAR/ucar_summary.pdf> [29 December 2004].

Department of Defense. *Defense Science Board Study on Unmanned Aerial Vehicles and Uninhabited Combat Aerial Vehicles.* Washington, DC: February 2004.

Department of Defense. *Unmanned Aerial Vehicles Roadmap 2002-2027*. Washington, DC: December 2002.

Department of Defense. *Department of Defense Dictionary of Military and Associated Terms*. Joint Pub JP 1-02. Washington, DC: 12 April 2001, As Amended Through 30 November 2004.

Department of the Navy. *The Commander's Handbook on the Law of Naval Operations*. NWP 1-14M. Naval Doctrine Command. Norfolk, Virginia: October 1995.

Friedman, Norman. "Paris Air Show Highlights Networked Warfare." *United States Naval Institute Proceedings*. Annapolis: August 2003. ProQuest. [30 April 2004]

Fulghum, David A. "Advanced UAVs." *Aviation Week & Space Technology*. New York: 20 September 2004. 46-48.

________. "Predator B to Increase Lethality of UAV Fleet." *Aviation Week & Space Technology*. New York: 11 November 2002. 34. ProQuest. [28 December 2004].

________. "War from 60,000 Ft. Exclusive images show off Global Hawk's updated package of infrared, electro-optical and radar sensors." *Aviation Week & Space Technology*. New York: 8 September 2003. 54. ProQuest. [11 May 2004].

Future Combat Systems (FCS). Lkd. GlobalSecurity.org. <http://www.globalsecurity.org/ military/systems/ground/fcs.htm> [19 October 2004].

Hewish, Mark. "Unmanned, Unblinking, Undeterred." *Jane's International Defense Review*. 01 September 2002. Lkd. Janes.com. <www4.janes.com/K2/doc.jsp?t=Q&K 2DocKey=/content1janesdata/mags/idr/history.htm> [12 May 2004].

Huber, Allen L. <allen.huber@us.army.mil> "RE: RFI." [Email to Barry Ezell <barry.ezell@us.army.mil>] 11 January 2005.

Johnson, William H. "UAVs Need Doctrine & Tactics." *United States Naval Institute. Proceedings*. Annapolis: April 2003. 37. ProQuest. [30 April 2004].

Joint Unmanned Combat Air Systems J-UCAS Overview. Lkd. DARPA.mil. <http://www.darpa.mil/j-ucas/index.htm> [29 December 2004].

Kelly, Scott K. "Future Capabilities and Roles of Uninhabited Combat Aerial Vehicles (UCAV)." Unpublished Research Paper. US Naval War College. Newport, Rhode Island: 18 May 2004.

Lamartin, Glenn F. Testimony before the House Armed Services Committee. United States House of Representatives. Subcommittee on Tactical Air and Land Forces. *Unmanned Combat Air Vehicle (UCAV) and Unmanned Aerial Vehicle (UAV)*. 17

March 2004. Lkd. GlobalSecurity.org. <http://www.globalsecurity.org/military/library/congress/2004_hr/04-03-17lamartin.htm> [26 May 2004].

LeBouvier, Rand D. “Unmanned Systems Extend Operational Reach.” *United States Naval Institute Proceedings*. Annapolis: June 2004. 36-39.

Lockheed Martin Corporation. *Lockheed Martin Demonstrates Collaboration of Manned, Unmanned Aircraft as Part of UCAR Development Program*. Company Press Release. Owego, New York: 23 August 2004. < http://www.lockheedmartin.com/wms/findPage.do?dsp=fec&ci=15708&rsbci=0&fti=112&ti=0&sc=400> [20 January 2005].

Moaveni, Azadeh. “They Didn’t Know What Hit Them.” *Time.* 18 November 2002. 58. ProQuest. [14 January 2005].

Munson, Kenneth, ed. *Jane’s Unmanned Aerial Vehicles and Targets*. Issue Twenty One. United Kingdom: Jane’s Information Group Limited, November 2003.

Parsch, Andreas. *Teledyne Ryan Q-2/KDA/xQM-34/BGM-34 Firebee.* Lkd. Designation-Systems.net. “Directory of U.S. Military Rockets and Missiles.” <http://www.designation-systems.net/dusrm/m-34.html> [14 January 2005].

Pinney, Chuck. *UAV Weaponization.* (Presentation delivered at International Air & Space Symposium (AIAA) “The Next 100 Years” 17 July 2003). Lkd. Raytheon.com. <http://www.raytheon.com/feature/stellent/groups/public/documents/legacy_site/cms01_042879.pdf> [28 December 2004].

Predator Unmanned Aerial Vehicle (UAV), USA. Lkd. Airforce-Technology.com. <http://www.airforce-technology.com/project_printable.asp? ProjectID=1137> [14 January 2005].

Rees, Elizabeth. “Air Armament Summit VI Culls Five Key Weapons-Related Trends.” *Inside the Air Force* via NewsEdge Corporation. 26 March 2004. [30 March 2004].

Robinson, Tim. “Getting Down and Dirty.” *Aerospace International*. December 2004. 18-21. Lkd. DARPA.mil. <http://www.darpa.mil/tto/programs/UCAR/gettingdown .pdf> [13 January 2005].

Roche, James G. “Applying UAV Lessons to Transform the Battlefield” (Remarks at Association of Unmanned Vehicles Systems International, Baltimore, Maryland. 15 July 2003). Lkd. FindArticles.com. <http://www.findarticles.com/p /articles/mi_m0PDU/is_2003_July_15/ai_109569822> [16 May 2004].

Selinger, Marc. “Jumper Confirms Air Force Plans to Cut Joint Strike Fighter Purchase.” *Aerospace Daily & Defense Report*. 15 December 2004. Lkd. Aviation Week’s AviationNow.com. <http://www.aviationnow.com/avnow/search/autosuggest.

jsp?docid=259625&url=http%3A%2F%2Fwww.aviationnow.com%2Favnow%2Fnews%2Fchannel_aerospacedaily_story.jsp%3Fview%3Dstory%26id%3Dnews%2FJSF12154.xml> [15 December 2004].

Small Diameter Bomb/Small Smart Bomb. Lkd. GlobalSecurity.org. <http://www.globalsecurity.org/military/systems/munitions/sdb.htm> [21 January 2005].

Sweetman, Bill. "In the Tracks of the Predator: Combat UAV Programs Are Gathering Speed." *Jane's International Defence Review*. 01 August 2004. Lkd. Janes.com <www4.janes.com/K2/doc.jsp?t=Q&K2DocKey=/content1/janesdata/mags/idr/history.htm> [21 January 2005].

Thurman, James D. Testimony before the House Armed Services Committee. United States House of Representatives. Subcommittee on Tactical Air and Land Forces. *US Army Unmanned Aerial Vehicle (UAV) Programs*. 17 March 2004. Lkd. GlobalSecurity.org <http://www.globalsecurity.org/military/library/congress/2004_hr/04-03-17thurman.htm> [16 May 2004].

United States Central Command Air Forces (USCENTAF) Assessment and Analysis Division. *Operation IRAQI FREEDOM – By the Numbers.* Prince Sultan Air Base, Kingdom of Saudi Arabia: 30 April 2003.

United States Air Force Air Combat Command. *Concept of Employment for the MQ-1 and MQ-9 Multi-role Endurance Remotely Operated Aircraft*. Langley AFB, Virginia: 2 May 2002.

United States Air Force Air Combat Command. *Enabling Concept MQ-9 Hunter-Killer*. Langley AFB, Virginia: 16 July 2004.

United States Air Force Air Combat Command. *MQ-1 Multi-Role Endurance Remotely Operated Aircraft Concept of Operations (CONOPS)*. Langley AFB, Virginia: 19 May 2003.

United States Air Force Air Combat Command. *MQ-9 Hunter-Killer Remotely Operated Aircraft Concept of Operations (CONOPS)*. Langley AFB, Virginia: 18 June 2003.

United States General Accounting Office. "Matching Resources with Requirements Is Key to the Unmanned Combat Air Vehicle Program's Success." Report to the subcommittee on Tactical Air and Land Forces. Committee on Armed Services. House of Representatives. Washington DC: June 2003. Report number: GAO-03-598.

________. "Improved Strategic Planning Can Enhance DOD's Unmanned Aerial Vehicles Efforts." Report to the Chairman, Subcommittee on Tactical Air and Land Forces. Committee on Armed Services. House of Representatives. Washington DC: March 2004. Report number: GAO-04-342.

________. “Major Management Issues Facing DOD’s Development and Fielding Efforts.” Testimony before the Subcommittee on Tactical Air and Land Forces. Committee on Armed Services. House of Representatives. Washington, DC: 17 March 2004. Report number: GAO-04-530T.

Waugh, Paul. *Challenges & Opportunities*. (Remarks prepared for delivery at DARPATech 2004 Symposium, Anaheim, California, March 9-11, 2004). Lkd. DARPA.mil <http://www.darpa.mil/ DARPAtech2004/pdf/scripts/WaughScript.pdf> [28 December 2004].